Frontier

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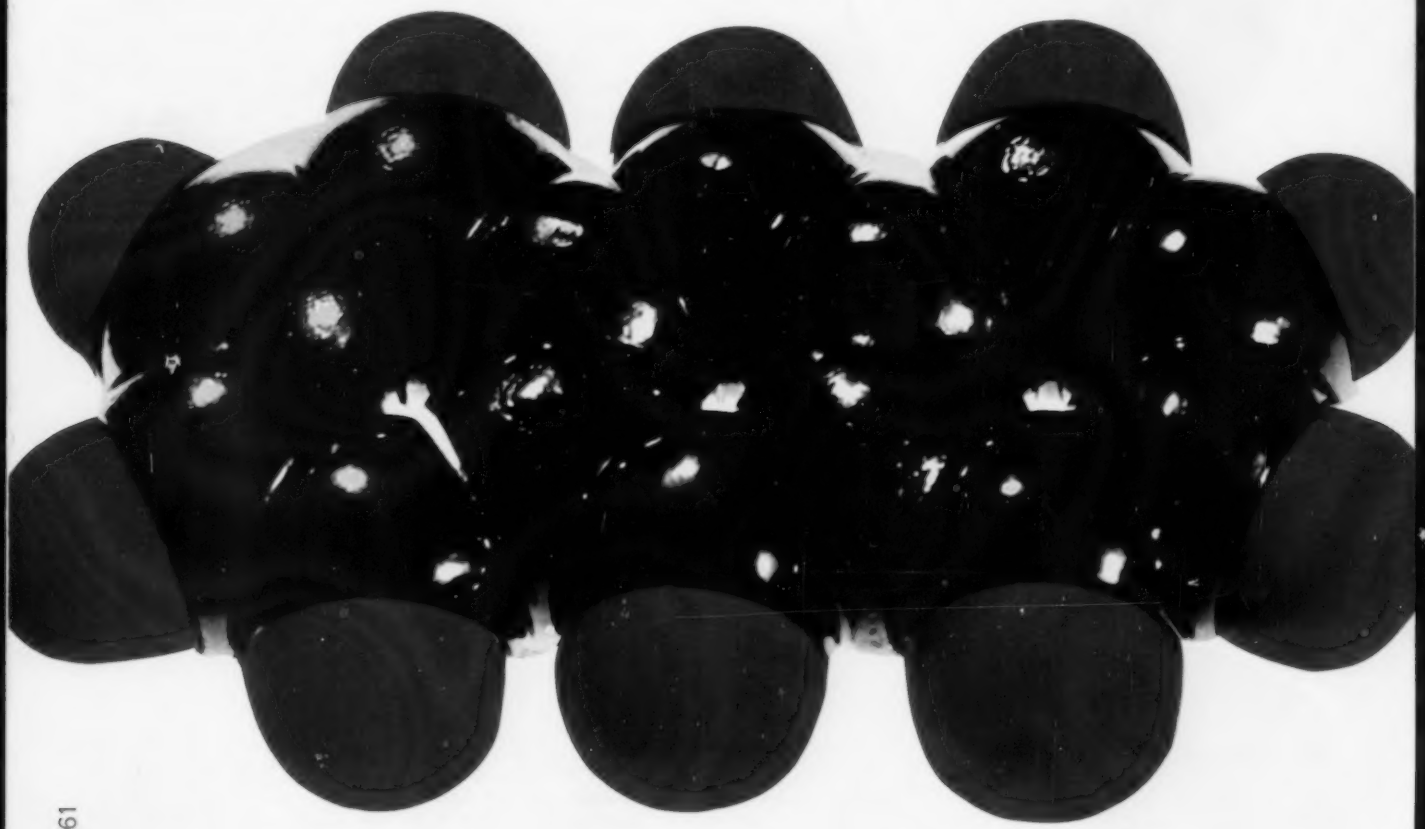
in this issue: research in organic semiconductor materials turns to anthracene



SUMMER, 1961

COMMENT

The first issue of FRONTIER appeared in February of 1938, long before its title had either political or space age implications. The title at that time was simply descriptive of the area in which work was being conducted at Armour Research Foundation: the frontier of man's knowledge.

ARF was then not quite two years old, having been chartered to conduct contract research in April of 1936. It was a healthy infant, precocious for its age, full of promise for the future. FRONTIER was brought into being to serve as a Boswell to this young Johnson.

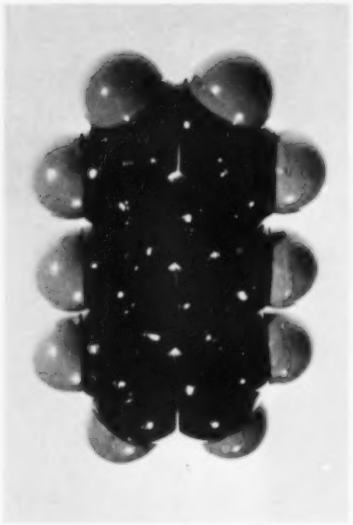
This year, ARF celebrates its silver anniversary, an occasion to be noted as a milepost in a corporate history and also as a stage of growth. ARF was developed as the research center for Mid-America; now it is international in scope and repute. Its twenty-five-year record: 10,000 investigations for 3,000 sponsors, with a research value exceeding $100 million.

FRONTIER has been redesigned and expanded, beginning with this issue. This action was taken partly in a sense of celebration, but more in an attempt to keep pace with burgeoning ARF. The publication which served to chronicle the efforts of the infant twenty-three years ago can no longer properly perform its task. The infant is now mature, exceptionally active, and still growing. The new FRONTIER will reflect its constantly expanding efforts.

AUTUMN ISSUE

In the Autumn issue . . . The first earth vehicle has been pointed at Venus; Mars is considered a a prime planet for exploration; and the surface of the moon will be probed shortly. What surface conditions will be found on the moon and these planets? Stripping away the fictions, Dr. Nicholas Weil summarizes our present knowledge, gained by observation and instrument measurement. Then, projecting this information, he describes the problems of landing astrovehicles on these bodies.

COVER—The first important results from organic semiconductor research have come from the intensive study of molecular crystals—especially anthracene, whose molecular structure is represented on the cover.



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ORGANIC SEMICONDUCTORS

After two years of fundamental studies into the electrical properties of organic materials, there are now important results to report about conduction in anthracene crystals

BY JAMES J. BROPHY

The current interest in organic semiconductors among scientists and businessmen alike is unusual, for as a scientific discipline, the study of organic semiconductors has not progressed beyond the basic research stage. No one has fabricated a practical device for them. No one is even planning to—right now. What is fascinating is the potential of these materials, which may eventually overshadow the successes of silicon and germanium as semiconductors.

This long-range potential is leading the semiconductor and chemical industries to invest time, money, and the efforts of top scientific personnel in extensive programs of basic research. Through fundamental study, they are confident of developing semiconductor materials different from the ones now in use. They believe that organics will open the semiconductor field to entirely different types of applications.

Organic semiconductors can be simply defined as solids containing an appreciable number of carbon-carbon bonds capable of supporting electrical conduction. They fall roughly into two groups: the molecular crystals, such as anthracene, and the polymers, from which plastics are made.

A semiconductor, in its ability to conduct electricity, stands between a good insulator and a good conductor. The mechanisms of electrical conductivity in inorganic materials, such as germanium and silicon, are well known, and as a result, their insulating and conducting characteristics have been carefully utilized to achieve close control of electrical current. In a transistor, for instance, this control results in amplification, previously achieved through the much more complicated vacuum tube. Even though such devices as transistors, diodes, and power rectifiers have been made from inorganic materials with great success, the relatively simple molecular structures of the inorganics have placed clear limitations on the kinds of applications which they can support. In contrast, the molecular complexity of organic compounds offers the possibility of numberless uses—*if* electrical conductivity in organics can be similarly understood and manipulated.

An ARF researcher uses a high-speed, high intensity flash to determine if Hall effect is present in anthracene.

When enough is known about the electrical properties of plastics to employ them in semiconductor devices, the results are likely to be amazing. An organic chemist, using his ability to synthesize molecules with nearly any atomic interrelationship, could custom-make a semiconductor material whose electrical properties matched the demands of a specific application. Taking advantage of such custom tailoring, the fabricator of electronic devices could allow his imagination to wander and could conceive of entirely new films, filaments, and molded shapes to suit particular purposes.

The potential inherent in organic semiconductors is doubly exciting because the transition from basic studies to practical devices might come much sooner than it did in the inorganics field. Organized investigation of organic semiconductors is now at the same level of development as inorganic research was in the 1930's (see chart), but the large body of semiconductor knowledge that has already been established is encouraging rapid progress. The chemical industry in particular is confident of its ability to turn the new knowledge gained from basic research to commercial advantage, since it already has a deep knowledge of organics gained through decades of research and industrial processing.

Future applications of organic semiconductors may now be generating enthusiasm among industrial executives, but the chief concern over their properties presently lies within the domain of the research scientist. How do organic materials conduct electricity? A part of that important question has already been answered. The answer may not seem significant to the casual observer, but to the research scientist it constitutes an early breakthrough in a discipline only twenty-four months old.

The breakthrough became apparent only recently —during a conference sponsored in April by Armour Research Foundation and *Electronics* magazine (a McGraw-Hill publication). Nearly 300 researchers from the semiconductor, electronics, and chemical industries gathered in Chicago to summarize organic semiconductor research and disseminate the latest information about this new field. Two papers presented there demonstrated that theoretical considerations about the mechanisms of electrical conduction in molecular crystals coincided with observed characteristics of anthracene, the main organic semiconductor under study. The results of research presented in these papers are significant because for the first time electrical conductivity in one organic semiconductor has been understood.

The key word to electrical conductivity in inorganic semiconductors is *overlap*. Overlap is simply that area where the paths of electrons from different molecules (or atoms) cross. Under the right conditions electrons wandering at the periphery of a molecule may be assumed into the swirl of electrons associated with another molecule. A flow of these electrons moving from one molecule to another comprises electrical conduction.

The breakthrough consisted of an accurate calculation of how these electrons move in anthracene. An educated guess was made as to the probable paths of the electrons at the periphery of anthracene molecules. Through mathematical calculations the degree of likelihood for overlap was measured between electron paths associated with different molecules in a single anthracene crystal. Through these calculations the direction of the overlap was also predicted. Finally, these predictions—that there was a high degree of overlap, making the conduction of electricity possible, and that the overlap was likely to be in only one direction within the molecule—were verified by observed phenomena in molecular crystals.

These results are all the more outstanding because techniques familiar in inorganic semiconductor research were used, even though the bonding between molecules in anthracene differs markedly from that in germanium and silicon.

Anthracene has been a popular material for study because it is one of the simplest organic compounds. Only the molecular structures of benzene and naphthalene are simpler, but being less stable compounds, they do not make practical semiconductors. Anthracene, on the other hand, is stable, is grown in single crystals, and is representative of the large class of aromatic compounds. Furthermore, its physical

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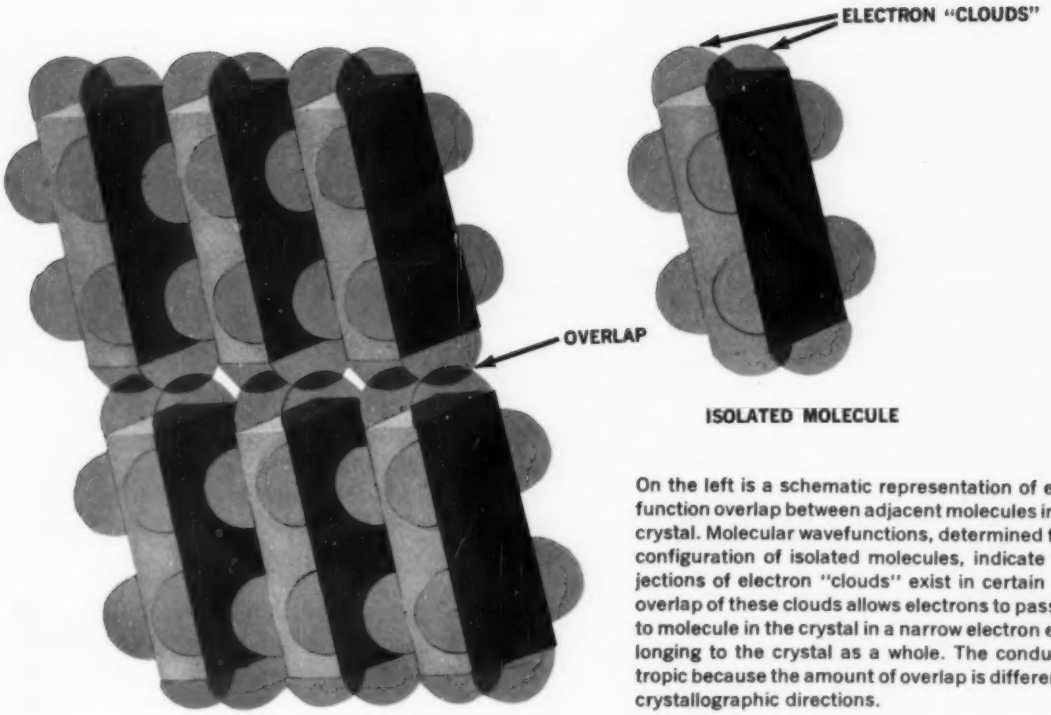
Dr. James J. Brophy, Director of Technical Development at ARF, is well qualified to discuss the research successes in organic semiconductors. He was co-chairman of the Inter-Industry Conference on Organic Semiconductors, the first comprehensive seminar in this country on this new discipline. He also has published widely in solid state physics, especially on problems of semiconduction.



On the left is a schematic representation of electronic wavefunction overlap between adjacent molecules in an anthracene crystal. Molecular wavefunctions, determined from the atomic configuration of isolated molecules, indicate that small projections of electron "clouds" exist in certain directions. The overlap of these clouds allows electrons to pass from molecule to molecule in the crystal in a narrow electron energy band belonging to the crystal as a whole. The conductivity is anisotropic because the amount of overlap is different in the various crystallographic directions.

properties are well understood. The spacing between carbon atoms in anthracene, for instance, is known within .01 of an angstrom (that is, within approximately .0000000001 of a centimeter).

But most important, the structure of anthracene is well-ordered. In contrast, the molecular structures of most organic compounds are enigmatic to the semiconductor researcher. Since organic compounds are usually precipitated out of solution and then pressed into pellets for study, the researcher may have only the vaguest notion of the physical properties of the substance before him. By applying heat or light to excite its electrons, he may actually cause an unwanted chemical change.

If the discoveries made about anthracene and molecular crystals are encouraging, the lack of knowledge about polymers and plastics is at present disheartening. Their complexity, which is the basis for their potentially wide range of applications, is a deterrent to accurate electrical measurement. Conduction in about 100 materials, obtained by chemical synthesis or pyrolysis, has been observed, but the level of conductivity usually has been low. Most discouraging, however, is the indication that the mechanisms of electrical conduction in polymers are entirely different from those in molecular crystals.

Experimentation with organic semiconductors has led to a number of realizations. Industrial management and researchers alike were hoping that the purity necessary in germanium and silicon semiconductors would not have to be met in organic materials. Such purity is spectacular; boron, for instance, must not exceed one part in 100 million in silicon. This attention to purity in semiconductors is necessary since it is electrons from the impurities in

inorganic semiconductors that actually carry the electricity. Because the amounts of impurities needed are so small (in a typical silicon transistor, arsenic, or some other impurity, accounts for considerably less than .001 percent of the silicon), the material into which the impurity is introduced must be superpure. Present studies of organic semiconductors indicate that comparable purity in materials must be achieved before conductivity in polymers can be properly studied, evaluated, and employed usefully in devices.

Another realization has been that organic chemists must learn more about semiconductor physics and that physicists must relearn organic chemistry, since the vocabularies of the physicist and the chemist have in many respects become distinct in regard to organic materials. Communication must be re-established between them before any real degree of success can be realized.

Although present results of organic semiconductor research are not applicable as such to semiconductor devices, the prospect of developing useful devices is encouraging. Now that the semiconducting properties of one organic material have been predicted, the possibility is that electrical properties of other compounds may be similarly foretold. The time is approaching when the solid state physicist can build theoretical models of organic compounds that will make good conductors of electricity and give the problem of their fabrication to the organic chemist. The organic chemist needs such positive direction. There are over 900,000 separate organic compounds now classified, and new ones are being added at the rate of 10 or 15 a day. The problem of deciding which compounds to study is in itself serious.

What will organic semiconductors look like once they have been developed and perfected as useful devices? It is far too early to make safe predictions, except that when applications are made, they will probably differ considerably from their inorganic predecessors. The organic transistor, although it can not be categorically ruled out, is an improbability. Electric cooling and solar generation of heat, on the other hand, loom as likely possibilities because of the low thermal conductivity of organics. As of now, no organic material has exhibited the needed combination of high electric conductivity and high thermoelectric power, though many compounds have shown one or the other characteristic. As the science progresses, however, it is likely that organic materials will be found that are adaptable to thermoelectric applications.

The future of organic semiconductors remains unpredictable because of the flexibility and complexity of organic materials. When electrical conductivity in polymers and plastics is better understood, man's imagination may be taxed to exhaust the uses for organic semiconductors. It is conceivable, for instance, that paints could be manufactured that contain a semiconducting material. Exterior house paint could collect the energy of the sun and turn it into heat. Interior walls, coated with a different paint, could be cooled electrically and with great simplicity.

Organic semiconductors may also have remarkable uses in the life sciences, for many of the basic life processes are electrical in nature. Chlorophyl, the substance responsible for food synthesis in plants, is basically a semiconductor.

Even in the unlikely event that only a few organic semiconductor devices reach the practical stage, there is yet a strong reason for extensive research activity. This is the improved, detailed understanding of organic materials sure to follow from the new laboratory techniques being developed to study these materials. In the past, electrical measurement techniques and the information they have yielded have proved to be of incalculable value in the study of solid materials, such as metals and ceramics, even though they were developed to examine silicon and germanium. Similar benefits are anticipated in the organic field, where electrical measurement techniques have been little used or understood in the past. Results based on the extreme sensitivity and variety of electrical measurements cannot fail but contribute to new and improved organic materials for all applications.

But no matter what is learned about electrical conductivity in organic materials, new laboratory techniques and new applications—perhaps undreamed of today—will follow from basic research. It is this certainty which has made the study of organic semiconductors, a young scientific discipline, an interesting subject to both scientists and businessmen.

INORGANIC SEMICONDUCTORS

1920-1930
Sporadic observations of semiconductivity; particularly copper oxide and selenium.

1925-1935
Simple semiconductor devices; copper oxide rectifiers, selenium photocells.

1931
Detailed understanding of differences between metals, insulators, and semiconductors.

1940
Detailed understanding of semiconductivity.

1944
Effect of chemical impurities in silicon and germanium; studies by K. Lark-Horovitz.

1944
Silicon and germanium point-contact diodes.

1947
Discovery of transistor by J. Bardeen, W. Brattain, and W. Schockley.

1950
Theory of minority and majority carriers; p-n junction transistors and diodes.

1950
Development of ultrapurification techniques; W. Pfann's zone refining.

1951
Other devices—solar cells, thermoelectrical cooling.

1952
Discovery of intermetallic semiconductor compounds by H. Welker.

1958
More devices—parametric diodes and tunnel diodes.

1960
Thin semiconducting films, epitaxial film growth, new transistor configurations.

ORGANIC SEMICONDUCTORS

1930-1959
Sporadic studies of conductivity in organic materials.

1960
Preliminary development of pure molecular crystals and experimental measurements by R. Kepler.

1961
Basic understanding of conductivity in molecular crystals in terms of molecular structure.

Semiconductivity was observed in inorganic materials as early as 1920. The cat-whisker radio was nothing more than a point-contact diode of lead sulfide. Lead oxide, selenium, and germanium were also commonly recognized semiconductors. But it was with germanium that the first intensive search into the electrical properties of semiconductors was made, and it was because of the success of the germanium transistor that general interest in semiconductors of all types has developed.

The history of inorganic semiconductor research began in the 1940's with the studies of K. Lark-Horovitz, a professor at Purdue University. Directing a group of graduate students, he charted the effects of impurities on the electrical properties of germanium by systematically "doping" germanium with varying amounts of each of the elements. In this way, an accurate knowledge of electrical conductivity in one semiconductor was gained.

A few years later, scientists in Bell Telephone laboratories, inspired by Lark-Horovitz's work, studied the electrical surface effects of germanium by using sharpened tungsten probes carrying voltages. Through this research, the point-contact transistor was discovered.

The discovery of this device led to a great increase in semiconductor research, which resulted in the development of the p-n junction transistor and all the other semiconductor devices now in common use.

Organic semiconductor research has started out on an entirely different footing. Whereas there were relatively few known inorganic semiconductors in 1940, there are now perhaps 100,000 organic materials in which some amount of conductivity has been observed. The trend has been to look briefly at an abundance of materials.

The real developments in organic semiconductors, however, have come by studying one material thoroughly—anthracene. R. G. Kepler of E. I. du Pont de Nemours and Company undertook the difficult task of making measurements of electron and hole mobility in anthracene crystals. Oliver H. LeBlanc, Jr., of General Electric Research Laboratory, applied the traditional theory of electron orbital overlap to anthracene. His interpretation agreed with Kepler's measurements.

These calculations and interpretations amount to a breakthrough in the detailed understanding of semiconductivity in organic compounds.

ELECTROMAGNETIC COMPATIBILITY

In recent years, the vastly increased power, sensitivity, and amount of new electronic equipment have created an RFI crisis now being met by an extensive compatibility program

BY STANLEY I. COHN

Can we afford to crowd ourselves out of the radio frequency spectrum?

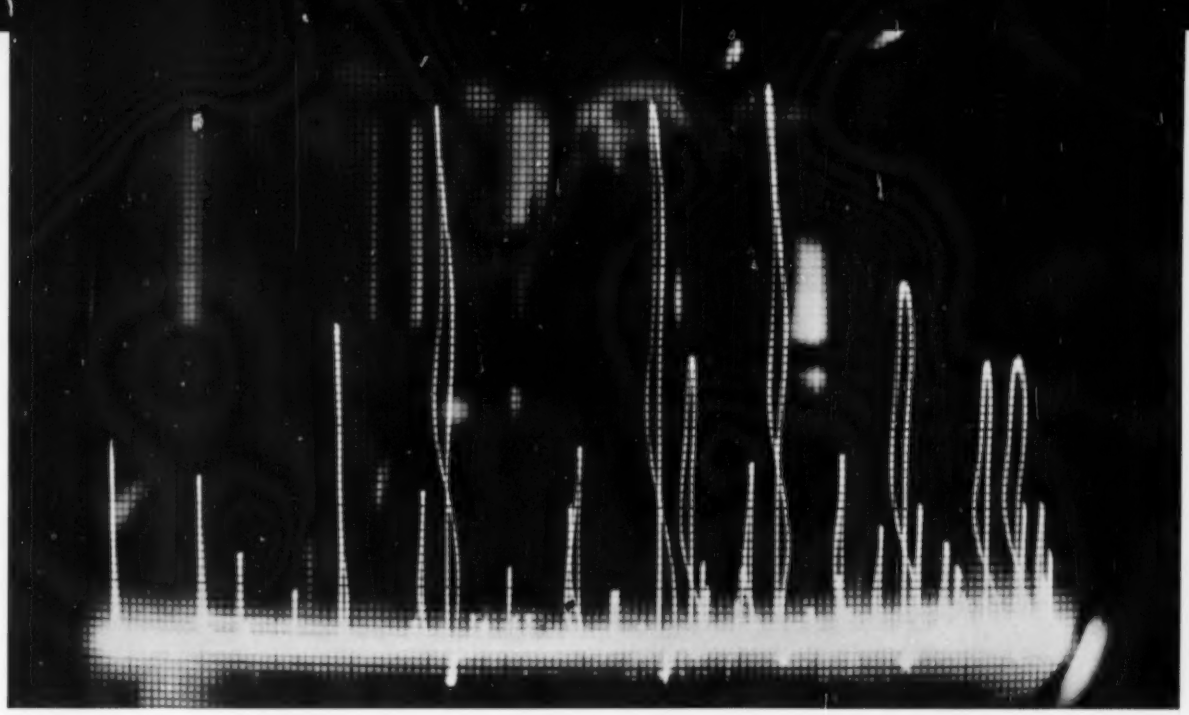
Today that is the most pertinent question in the electronic field where radio frequency interference (RFI), which has always been an annoyance, has now become a major problem. With the ever-increasing number as well as the growing sensitivity of electronic installations, radio interference problems have multiplied drastically. Missile failures, communication jamming, radar blanking, collisions at sea and in the air are but a few of the catastrophes directly traced to RFI.

Since the early days of wireless communication at the turn of this century, interference has created an annoyance in one form or another. In those days, moving to an unused higher frequency provided a temporary solution. This practice alone was primarily responsible for the exploration of new frequency spectra constantly moving toward the wavelength of light. By the early 1920's, the frontier had been pushed to the 10 megacycle range. By the early 1930's, to the 30 megacycle range. And by the early 1940's, developments in the 200-600 megacycle range were well established. The advent of World War II was accompanied by an additional push of the spectrum to accommodate new forms of information retrieval, such as radar.

On the heels of increased spectrum development for relief of congestion came two more factors that compounded the problem at a tremendous rate. To obtain greater range both transmitter power and receiver sensitivity were increased. These factors contributed significantly to the RFI problem.

Although the compounded results are obvious, integrated efforts to overcome the mounting difficulties have evolved slowly. During the late 1940's the problem was recognized by various groups both in the military and in industry. Generated out of the resulting concern was a trj-service contract issued to the Armour Research Foundation in 1953. It was initiated to determine the magnitude of the problem, to obtain recommendations for investigation in technical and administrative areas, and to obtain recommendations for establishing a suitable interference reduction program.

Additional orientation on interference came in 1954 through the organization of the First Confer-



Panoramic display of a portion of the spectrum at Cape Canaveral seen on a spectrum analyzer, showing amplitude of signals in a 160 megacycle band. Crowded conditions that contribute to the compatibility problem at this vital military base are clearly indicated.

ence on Radio Frequency Interference, jointly sponsored by government agencies and ARF. Other similar conferences have since taken place, and important advances have been made in suppression techniques.

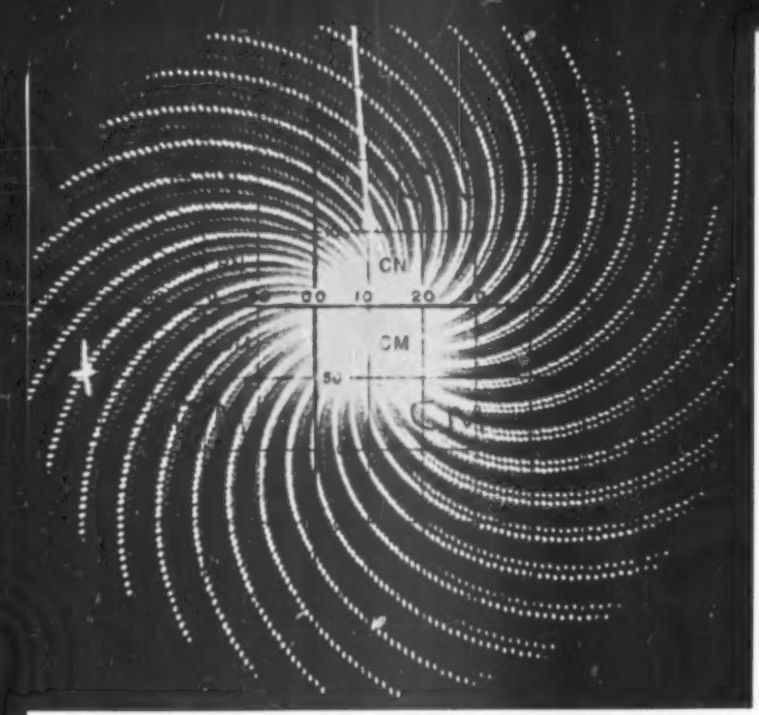
The most significant move toward the control of RFI, however, is evolving out of the decision of the Department of Defense (DOD) to unify the efforts of all three services in an overall electromagnetic compatibility program. At the hub of this program is the establishment of the Electromagnetic Compatibility Analysis Center at the U.S. Naval Engineering Experiment Station in Annapolis, Md. The technical operation of this facility is to be conducted by ARF, which has been awarded a $2 million contract for this purpose by the Electronic Systems Division (Hanscom Field, Mass.) for the Air Force Systems Command.

The activities of the Analysis Center will necessarily focus on determining the degree of electromagnetic compatibility—i.e., interference-free operation—in existing and proposed military situations. The degree of compatibility, however, is not the only concern. What must be resolved is the realization of electromagnetic compatibility for a given military situation. To this end, the Analysis Center will team technical and administrative talent for developing and applying techniques relevant to the solution of an immense accumulation of existing and forthcoming RFI problems.

This facility will include not only 80 to 90 technical personnel trained in the use of electronic and mathematical techniques, but also a large digital computer facility. The Analysis Center will be responsible to the DOD through a director supplied by the military. The director will report to the DOD and the Joint Chiefs of Staff. The Army, Navy, and Air Force will each have a support group that can contact the Analysis Center directly with problems.

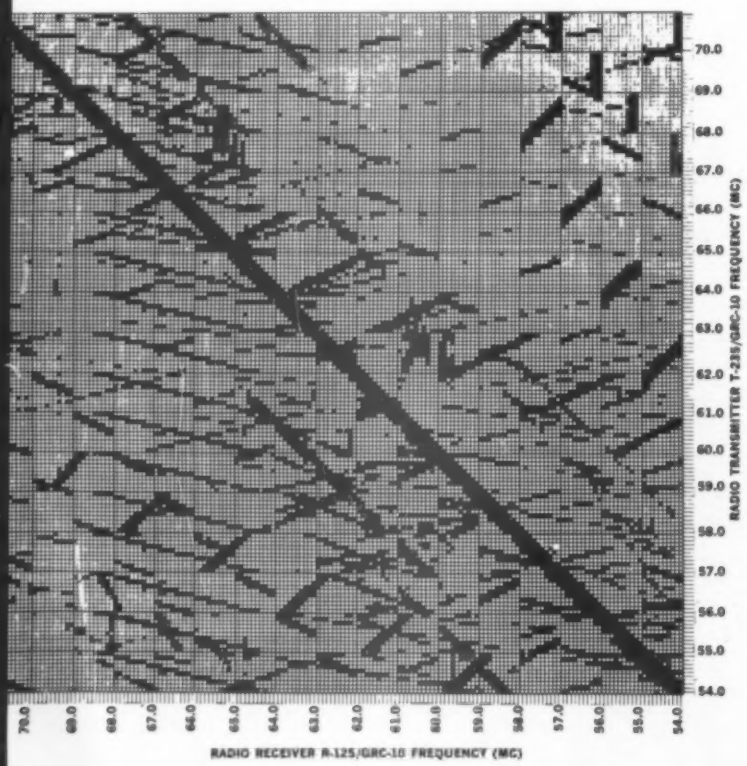
Assistance in establishing the Electromagnetic Compatibility Center will be provided by the Engineering Experiment Station of Georgia Institute of Technology, which has been subcontracted for this endeavor by ARF.

To understand the various functions that must be performed at the Center, it is best to consider first the given input and output information required. Input information consists basically of military situations and equipment deployment (envi-



A target aircraft appearing as a dot on this radar scope would be impossible to identify among the numerous dots caused by RFI.

Blackened areas on mutual interference chart indicate frequencies at which interference will occur at the receiver for any given transmitter frequency. Chart is read by selecting a transmitter frequency *(at right)*, moving across the chart and noting which receiver frequencies correspond to the darkened areas.



ronmental data) as well as the data regarding the characteristics of electronic equipment (spectrum signatures). The required outputs are descriptions of environmental interaction, frequency allocation data, operational procedures needed to increase compatibility, and possible interference and susceptibility reduction measures for offending equipment. From these results better utilization of the radio frequency spectrum, both in the frequency allocation and equipment characteristics areas, should be obtained. Although initial emphasis will be placed on radar, the Analysis Center will eventually attack problems in the communication area.

Since the spectrum signatures of equipment are rather complex and hand calculations of the interaction of equipment are quite lengthy, it is obvious that automatic processing must be used to evaluate compatibility in any realistic military situation. This requires that spectrum signatures and environmental data must be maintained in a central library in a form that is suitable for a computer. In order to process these data one must use a mathematical model which is a computer representation of the situation and physical phenomena to be analyzed.

Data processing techniques for analysis of compatibility are relatively new, and effort must be directed toward refining these and developing more sophisticated computer programs for analysis. In addition, techniques of operations research must be developed and applied to determine optimum frequency allocations and operational procedures that will enhance compatibility. Methods of handling the immensely complex results of the analysis must also receive consideration. This requires research in the application of data read-out systems, map printing, and environmental display techniques to facilitate comprehension of staggering quantities of interrelated data.

Another factor that will be considered is the validity of the data to be used. As experience is gained in compatibility analysis, the accuracy and types of data required will change in order to obtain more meaningful results. The Analysis Center staff must respond to these changes by aiding in revisions of data collection standards, both in the spectrum signature and environmental data areas. Measurement techniques must be reviewed and revised periodically, taking into account resulting data accuracy, ease of measurement, and instrumentation requirements.

It is anticipated that the analytical results will point up problems in equipment characteristics. Possible corrective measures for reducing interference susceptibility and undesired radiation must be proposed. These may take the form of equipment circuit modifications or addition of selective filters. In certain cases, it may be wise to replace certain types of equipment because of poor compatibility characteristics.

In the case of equipment under development, compatibility analysis can be a design aid by pointing out which equipment characteristics need improvement. Along these lines, technical personnel must not only be familiar with the state of the art in interference reduction but must also be aware of new equipment developments. New techniques in the rapidly changing electronics art must be examined for possible interference problems so that electromagnetic compatibility will be considered by the designers of future complicated equipment. This is of paramount importance since equipment designed for compatibility will cost far less than equipment that has to be modified to reduce interference.

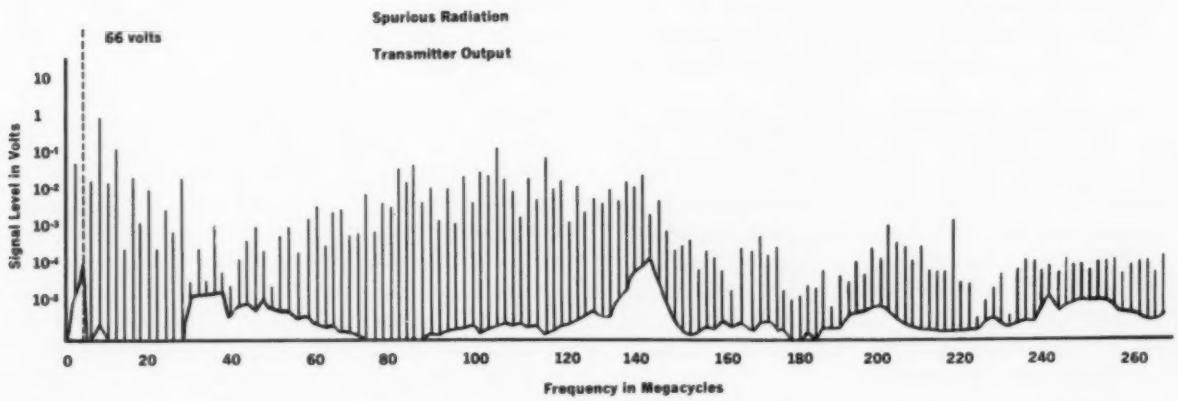
The knowledge that the Electromagnetic Compatibility Analysis Center will accumulate must be made available to others concerned with various facets of the overall compatibility program if the maximum benefit is to be obtained. To this end the Analysis Center must aid the military services by providing required consultant services and by preparing information to be included in manuals and specifications.

Anticipated areas of consultation include equipment standards, measurement techniques, instrumentation, data collection methods, interference reporting techniques, field tests, susceptibility and interference reduction techniques and devices, transmitting and receiving equipment, future equipment requirements, simulation methods, and design procedures for equipment.

Obviously the present dilemma in the electronic field is both extensive and intricate. The answer to the question, "Can we afford to crowd ourselves out of the radio frequency spectrum?" is also clear. To escape chaos, complete control of RFI will be a necessity in the coming years as the frequencies of countless new devices are crammed into an already crowded spectrum. And to realize the full potential of the ultra-sensitive electronic equipment in advanced radar systems, world-wide communication networks employing satellites, and in interspacial contact, we *must* obtain electromagnetic compatibility. The first major step toward this objective is the initiation of the DOD compatibility program and the establishment of the Electromagnetic Compatibility Analysis Center.

Since 1956, Stanley I. Cohn has been assistant director of Electronics Research at ARF. He has worked in the fields of radar, communications, microwaves, antennas, and propagation as well as radio frequency interference. He is now the director of technical operations for the Electromagnetic Compatibility Analysis Center.

Graph demonstrates the amplitudes of the undesired frequencies generated by a radio transmitter. Ideally, transmitter would generate energy at the assigned frequency of four megacycles rather than spurious energy over the wide range shown.



LABORATORY LOCATION

When selecting the location of a new research laboratory, corporation management must consider many factors. Most important is the relation of the site to personnel needs

BY GEORGE PHILIPS

Research is one of the most powerful competitive tools available to management today. Through improved quality, reduced costs, or the development of a whole new line of products and markets, it allows a company to compete on a number of fronts. By the same token, research eventually affects every facet of a company's operation from engineering through sales. It is therefore important that a company's entire research program and policy be carefully and purposefully planned by management—starting with the location of the physical facilities.

The selection of the appropriate geographic location and the specific site for a research facility is a unique process. Unlike the case of locating production plants and warehouses, optimum research locations cannot be measured and projected. Each candidate research site can be evaluated only in terms of its likely over-all contribution to company stature and profits. This, in turn, can best be measured by evaluating its ability to attract, develop, and retain capable personnel.

In a study recently completed for the Liquid Carbonic Division of the General Dynamics Corporation, the Armour Research Foundation identified a number of factors which a research site should possess to best meet the needs and desires of executive management, the research director, and the scientific staff. Representatives of over 50 companies which have recently located or relocated research facilities were interviewed in the course of this study. Several of the more significant findings are presented below.

It appears that general geographic location, such as the far West, South, or Northeast, is, in itself, of little importance in terms of locating a research facility. The research engineer and the scientist are attracted to a position primarily on the basis of the nature of the work that is involved and over-all management research policies. All other things being equal, the mobility of the technical community is such that capable personnel can be attracted to most areas of the United States. It is on the regional

level that the factors important for the effective operation of a research laboratory come into play.

From the corporate point of view, four factors were identified in the ARF study as being most important.

1. The research laboratory should be neither too far from, nor too near to, corporate or division headquarters or production facilities. As a rule of thumb, the research facility should be an hour to an hour and a half away from any major company activity. This factor of time and distance provides the laboratory sufficient isolation from day-to-day operating problems: the laboratory is not called to put out manufacturing "brushfires." At the same time, the laboratory must be close enough to permit necessary visits from key management and production people.

2. The research laboratory should be located in a community where a friendly environment and political attitude have been demonstrated to similar laboratories. In the past, when care has not been taken in this regard, laboratories have been faced with the necessity of maintaining an expensive educational and public relations program in dealings with the community—primarily in distinguishing the laboratory from general industry.

3. The laboratory should be accessible by normal methods of transportation, whether by highway or public transportation. This is a factor in the recruitment of all levels of laboratory personnel, in visits from company personnel, supplier representatives, and others. If laboratory people are called upon to travel, or if out-of-town visitors are likely to be frequent, accessibility to major airports is also important.

4. General characteristics to be considered in the actual site selection include its general attractiveness, the opportunity for expansion, the availability of utilities, the total cost of land and construction, and taxes. The evaluation of a neighborhood's attractiveness includes the desirability of present neighbors and indications of the future development of the neighborhood.

From the research director's point of view, there are three major requirements to be considered.

1. The research directors who were interviewed showed almost complete unanimity on the importance of easy accessibility to universities. There are three strong reasons for their concern:

a. The availability of night courses for the research staff.

b. The availability of literature sources and of special facilities.

c. The availability of technical non-professionals and professional people either to be recruited or to be employed on a continuing basis.

The laboratory should be located within thirty minutes driving time of a university to take best advantage of these factors.

2. The research laboratory should be located in an area where manual and clerical workers are available. In the major effort to attract a top professional staff, this factor may be overlooked—yet it is of great importance. It was found that while professional people will generally commute up to 20 miles, the range of clerical and particularly of laboring personnel is more limited, averaging under 10 miles.

3. There should be readily available to the site the outside services upon which a laboratory de-

RANKING OF SITE LOCATION CRITERIA

ORDER OF IMPORTANCE	CRITERIA	VALUE ASSIGNED	IMPORTANT TO
1.	SOCIAL, CULTURAL, AND GENERAL LIVING CONDITIONS OF THE AREA	0-15	RESEARCHER
2.	ACCESSIBILITY TO MAJOR UNIVERSITIES AND LIBRARIES	0-10	RESEARCHER & RESEARCH DIRECTOR
3.	GENERAL SITE CHARACTERISTICS: SITE TOPOGRAPHY 5 NEIGHBORHOOD 4	0-9	MANAGEMENT
4.	COMMUNITY ATTITUDE TOWARD RESEARCH LABS	0-8	MANAGEMENT
5.	GENERAL ACCESSIBILITY: HIGHWAY 3 PUBLIC TRANSPORTATION 3 MAJOR AIRPORTS 1	0-7	MANAGEMENT
6.	PROXIMITY TO DIVISION HEADQUARTERS	0-6	MANAGEMENT
7.	AVAILABILITY OF NON-PROFESSIONAL LABOR SUPPLY	0-6	RESEARCH DIRECTOR
8.	AVAILABILITY OF SPECIAL SERVICES	0-2	RESEARCH DIRECTOR
	TOTAL	63	

In this case involving the Chicagoland area, important criteria were charted to progressively narrow down area before selection of specific site for proposed research laboratory. First chart maps area 15 to 40 miles from company headquarters. Second chart narrows down this area by showing part located within 25 miles of major universities.

pends—machine shops, maintenance services, chemical supply houses, and the like. Oftentimes, the role that such services play in the smooth operation of a laboratory is recognized only when they are disrupted or when painful experience eventually proves them to be inadequate.

From the point of view of the scientists and the engineering personnel, there are several important factors in choosing a place of employment.

Social, cultural, and general living conditions are those intangible factors that pertain, not to a man's work per se, but to where he lives, how he lives, and what kind of satisfaction he derives from his social and cultural environment. The most important of these factors are the following:

1. Adequate primary and secondary schools (rated very high).

2. A satisfying cultural or intellectual environment. Research personnel desire the stimulation of association with people of similar intelligence and background. As a group, they are more likely than not to be interested in cultural activities.

3. Housing to accommodate several economic levels.

4. Recreational and religious facilities.

5. General attractiveness of the area.

The above factors need not necessarily exist within the immediate area of the laboratory location. Professional people, as was mentioned earlier, appear to be willing to commute 20 miles to work. Nonetheless, it is reasonable to say that the shorter the distance to commute, the more attractive the job becomes. The distance from home to laboratory should not inhibit the researcher's desire to work late or to return to the laboratory at night.

It should be pointed out that not all of these factors must be met by the community within

ARF survey indicated that laboratory should not be built in area in which heavy industrial growth might be expected. Such parts of Chicagoland are shown in chart three. The area that remains in chart four is the general locale in which field work was undertaken by management to locate best laboratory site according to specific company needs.

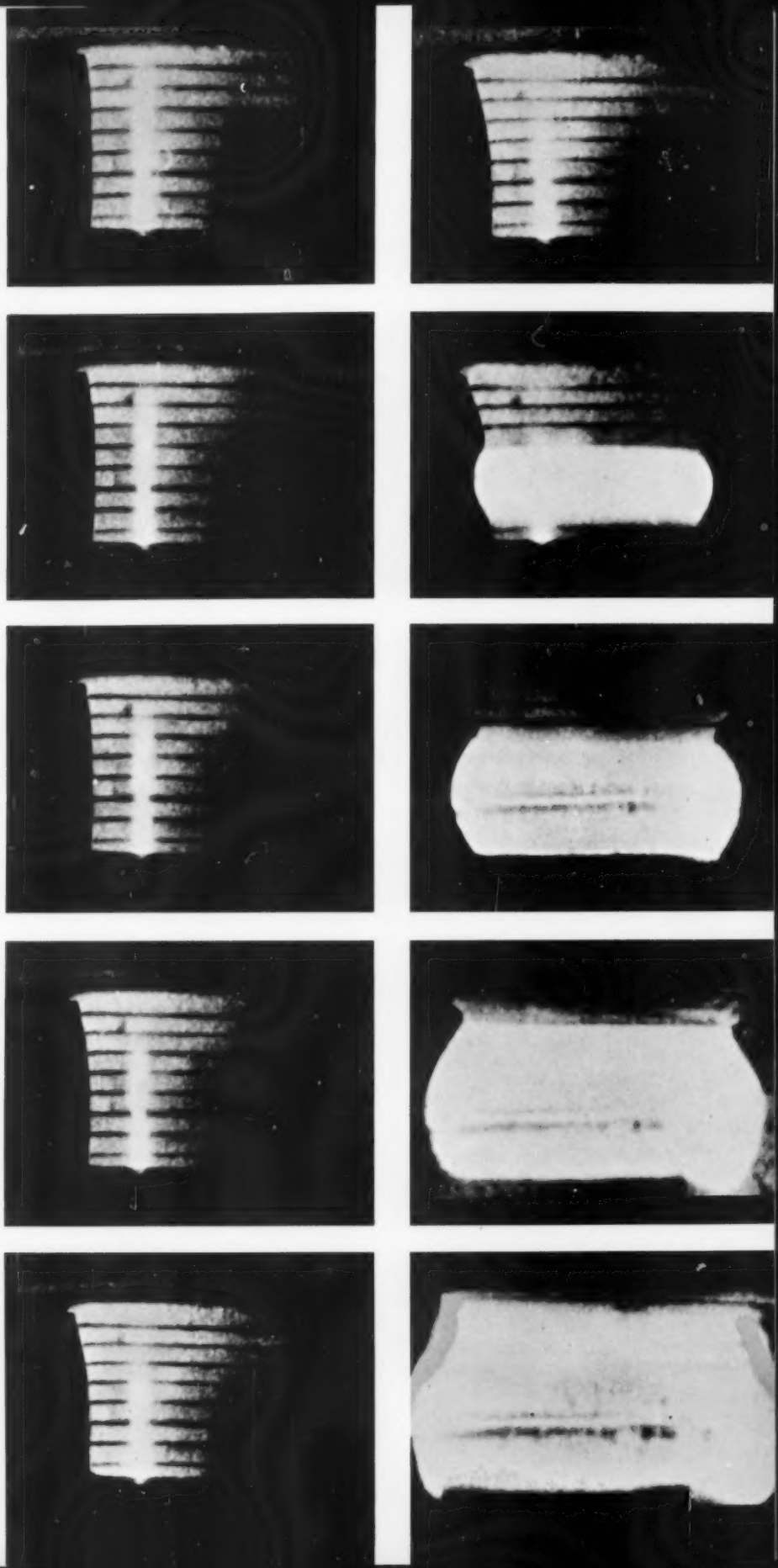
which the laboratory is located. These are desirable aspects of a general area, and it can be presumed that the researcher will locate in that part of the area where his particular needs are best met.

Naturally, not all of the above factors are of equal importance in evaluating alternate research sites. A consensus of those who participated in the ARF study placed the greatest emphasis upon fulfilling the immediate personal desires of the professional staffman and upon allowing an opportunity for his professional development. A listing of the composite relative weights assigned to each of the eight main factors is presented in the accompanying table.

Naturally, this composite evaluation serves only as a frame of reference for a company considering the location or relocation of its specific facilities. Each company must consider its own case in terms of its individual requirements.

The application of the above factors in a general geographic area will quickly and effectively identify several promising candidate sites. This mechanistic approach, however, is not capable of identifying the one most desirable site. The final judgment must take into consideration such intangible factors, among others, as the general esthetics of the site and its ability to project the desired corporate image. To gauge these factors, it is necessary for the top management, the research director, and the representative of the architectural firm commissioned to design the facility to personally visit each of the considered sites. The final decision can be reached only through the exercise of experienced management judgment.

George Philips is the assistant director of Techno-Economics and Management Research at ARF. Besides investigations along a broad front of management problems, his activities have included a comprehensive study of the economic potential for the entire State of Maine and an assessment of research communication channels of the United States Army.



Ten photographs taken in ten microseconds by Model 189 camera at rate of 1 million frames per second show mushrooming of explosive under impact prior to detonation, which begins in seventh picture. Sequence was illuminated by explosive flashlight.

EXPLOSIVE FLASHLIGHT

An explosive flashlight, using a new sheet explosive, has been developed to provide the needed illumination for a camera that photographs up to 4,300,000 frames per second

BY JACK GERSHON AND RICHARD H. STRESAU

Beyond the veil of human sight is a world of super velocity that is being revealed to man through etched fragments of motion on photographic film. Making a graphic record of an action that occurs during one microsecond (one millionth of a second) so that the eye can perceive it is now common in the modern research laboratory. Showing the continuous progress of a high velocity subject, however, is not common although an appropriate framing camera exists. The reason is that the large amounts of explosive materials needed to produce light of sufficient intensity and duration have made it impractical or impossible to photograph most super-speed subjects.

This does not apply if the subject itself provides sufficient luminosity, as do some explosives during detonation. Armour Research Foundation engineers conducting studies of the effect of impact on various types of high explosives realized, however, that their work would be handicapped if they were unable to observe the behavior of explosives prior to detonation. Therefore it was necessary to use an independent, controllable source of light having 25 to 100 microsecond duration and an intensity far greater than sunlight for these experiments, where detonation was expected to occur within tens of microseconds after the impact of loading.

Light of sufficient duration and intensity had already been produced with explosive argon flash-bombs, which have been widely used for photography involving microsecond exposures, but such large amounts of explosive material (six pounds or more) were required that the bombs could not be used at the Kingsbury Ordnance Plant, ARF's explosive research laboratory at La Porte, Ind., due to the proximity of plant buildings.

Consequently the research team directed its attention to sheet explosive for new possibilities in the design of more easily constructed and con-

venient light sources. Pursuing this line resulted in the development of a satisfactory flashlight at ARF employing only about two pounds of sheet explosive for 100 microseconds of light.

The explosive flashlight consists of a long acrylic plastic tube partially lined with the sheet explosive and filled with argon gas. When detonated, the sheet explosive acts as a shock initiator of the gas in the plastic tube. As the shock wave travels down the tube through the argon atmosphere it produces a light intensity close to 100,000 lumens per square centimeter, which is about 10,000 times brighter than direct sunlight on a subject.

Such intensity of light with a duration of 100 microseconds is more than adequate to overcome the small aperture and brief exposures of the Beckman & Whitley Model 189 framing camera used in these experiments, which is capable of taking pictures up to a rate of 4,300,000 frames per second.

Beckman & Whitley Model 189 framing camera in use in ARF laboratory during research project.

ARF explosive flashlight utilizes sheet explosive to ignite argon gas within plastic cylinder.

There are only about forty Model 189s in existence, most of them owned by the U. S. government. Essentially the Model 189 consists of 25 coordinated cameras built into one unit—that is, a camera with 25 film stations and 25 sets of matched achromatic lenses. The image is relayed through a 24-inch focal length objective lens to a polished metal mirror, mounted on a turbine that rotates at speeds up to 18,000 rps. From there the image is then successively relayed through the achromatic lenses to the film stations. Twenty-five separate exposures are therefore made, and at maximum speed the total recording time for the 25 frames is approximately five microseconds (1/200,000 of a second). By varying the turbine speed, the recording time can be as long as 500 microseconds. The effective aperture at each film station is f:16. The camera also has a streak attachment for the continuous monitoring of a subject.

The development of ARF's new explosive flashlight has led to a more thorough analysis of the behavior of explosive material and a greater knowledge of the nature of detonation than was possible in the past. But there is a need for an even more compact and efficient explosive flashlight for use in conjunction with ultra high-speed frame photography. The definitive objective of this basic research is to develop a self-contained flashlight unit that can produce sufficient luminosity with only a few ounces of explosive material. Once this has been accomplished ultra high-speed frame and streak photography will be feasible for almost any kind of appropriate laboratory work. Such photography will have applicability in many fields.

Jack Gershon and Richard H. Stresau developed the ARF explosive flashlight they have written about for the photographic work at the Kingsbury Ordnance Plant. Gershon is an experimental engineer who is ARF's expert on high-speed framing cameras. Stresau, presently a consultant for the Foundation, has devoted the past 15 years to intensive explosive study and experimentation. He is well known in the field of fuse design and is a recognized authority in the fields of explosive systems and components.

RESEARCH IN BRIEF

Armour Research Foundation undertakes research projects that encompass almost every scientific discipline. A few of its current projects are summarized below.

MAGNETOHYDRODYNAMIC GENERATOR

The Foundation is currently studying the combustion of coal at high temperatures and the ionization mechanisms, both thermal and non-thermal, that produce maximum ionization in combustion gases. The ultimate result of this study is the feasibility of a magnetohydrodynamic generator that utilizes coal as an inexpensive fuel.

A magnetohydrodynamic generator, in which ionized gases substitute for a wound armature, offers the advantage of converting heat directly into electricity without any intermediate moving parts. This mechanical simplicity would permit greater efficiency than is now possible with the conventional combination of steam turbine and generator. But the ionization necessary for such a generator is ordinarily produced at temperatures too high to be contained by present-day construction materials.

ARF researchers believe that coal may hold the solution to the ionization problem. The ash in coal, usually considered a deterrent to the efficient combustion needed in the magnetohydrodynamic generation of electricity, contains alkalies that, if properly utilized, could aid considerably in ionizing the combustion gases.

ARTIFICIAL ELECTRICAL NOSE

Long-range, fundamental work has been undertaken by ARF research personnel to understand, match, and eventually surpass the mechanism of olfactory sense. They are currently attempting to establish which groups of physiochemical surface interactions can exhibit selective electrical effects suitable for recognizing low concentrations of certain vapors in the air. Eventually, an "artificial electrical nose" may be developed, which would objectify the detection and analysis of odors. ARF researchers presently use a variable capacitance capacitator to compare contact-potential changes caused by the same vapor on several solids.

The eventual benefits from an artificial olfactory detector are enormous. Experienced doctors, for example, can recognize many sicknesses by the smell of the skin or body products. Large areas of diagnostics may thus be opened by objective olfactometry. Warning systems for toxic vapors in the air could be devised for industrial safety and for protection of military personnel. Olfactory examinations could also be made at a distance, as in space or other remote regions. Food aroma studies could be put on an objective basis, and methods of detecting food spoilage without extended tests might be developed.

Although the mechanism of olfactory sense is not yet fully understood, adsorption appears to be one link in the complex physiological process. ARF researchers theorize that adsorbent surfaces must exist that are highly selective with respect to molecular structures of adsorbed species. Since the final link in olfactory reception is an electrical impulse to the nervous system, it is probable that selective adsorption is signaled as a change in the potential of the interface.

COMPREHENSIVE VOLUME ON POINT IMPERFECTION

When a perfectly formed crystal of alkali halide, which is colorless, is subjected to X-rays a vivid color is produced. This is caused by divorcing a negative ion from the crystalline structure and at that point trapping an electron. Physicists call this an F center, which is a type of a "point imperfection."

There is a great body of information about the electrical, magnetic, mechanical, and optical properties of solids that are altered by point imperfection, which is relevant to basic research in photoconductivity, several types of magnetic studies, and all types of optical emission and absorption studies. Most of this data, however, is unintegrated.

Dr. Jordan Markham, ARF scientific advisor in the Physics Division, believes that an understanding of this point imperfection has been inhibited by the lack of a comprehensive text on the subject. Consequently he has gathered and collated all available literature related to the F center in alkali halides and is now working on a manuscript which, when published and distributed, will be a valuable research aid for scientists involved in the studies of solids.

NEW MISSILE CONTROL

An ARF research team is now engaged in experiments involving the development of a relatively simple inertial guidance system for ground support missiles. Current launching tests indicate that it will soon be possible to achieve greater accuracy with this system than with conventional "free rockets."

The inertial guidance system is not affected by countermeasures, such as jamming, except in the case of a direct kill. By virtue of its simplicity, it would be cheaper and easier to manufacture than "black box" (electronically) controlled missiles.

The team developing this guidance missile system includes William E. Reynolds, supervisor in the Mechanics Research Division; Fred King, senior scientist; and Seymour Bazell, design engineer. All three are extremely optimistic about the qualities of this inertial system as well as the eventual result of their work.

HANDBOOK ON THERMOPHYSICAL PROPERTIES

Thirty years have passed since the publication of the *International Critical Tables of Numerical Data*. These tables continue to serve the various sciences and technologies, but since their publication the amount of valuable numerical information, important for research and for design and engineering applications of all sorts, has increased tremendously. In an effort to make this information readily available, independent groups are consolidating and evaluating data in selected areas of science.

As a part of this effort, Armour Research Foundation has completed a five-volume handbook on the thermo-physical properties of solid materials (being issued as *WADD Technical Report 58-476*). The work was done under the sponsorship of Materials Central, Wright Air Development Division, U.S. Air Force. The 4,000 page book will soon be published in hardback form by the Macmillan Company.

The data was compiled from literature published during the period 1940-1957. The materials covered include elements, alloys, ceramics, cermets, intermetallics, polymerics, and composite materials. Except for the last two categories, only those materials whose melting points are above 1000°F are included.

Properties included in the compilation are density; melting point; latent heat of fusion, vaporization, and sublimation; transformation temperature; specific heat; thermal conductivity; thermal diffusivity; emissivity, reflectivity; linear thermal expansion; vapor pressure, electrical resistivity. Each reported value is shown and annotated, and recommended "most probable value" curves are given.

AFRICA

The new independent African nations face serious economic problems. Rich in resources but poor in education, these new nations need programs of intensive applied research

BY IRVING D. CANTON

The continent of Africa has been a prime target for exploitation by the major nations of the world since the time of Henry the Navigator, who first opened that portion of the continent south of the Sahara. But now the period of exploitation has passed, light is infiltrating the darkness, and Africa is rapidly becoming a continent of small, independent—and impoverished—nations.

There is no need for the poor economic conditions of these new nations to continue indefinitely. Each has natural and human resources which it must learn to use for its own benefit—and the key to this self-exploitation is *applied research*.

Typical of these new countries is Sudan, called the Anglo-Egyptian Sudan before achieving its independence in 1956, which has a population of 10 million and occupies nearly a million square miles in northeast Africa. The major crop is cotton, exported raw and with a minimum of processing, which accounts for better than 60 per cent of Sudan's export income. Second largest crop is gum arabic, representing 10 per cent of export income.

The agricultural potential of the country is large. Present crops are raised on only 3 per cent of the land area, while at least 35 per cent of the land is capable of cultivation. Developmental work is needed in farming techniques, irrigation, transportation, and communications to bring about an increase of agricultural production.

Differing from many of the other new nations of the continent, Sudan has relatively few known mineral and metal resources. Some effort has been devoted to exploring the development of these resources, but the potential in this direction is small.

The industrial growth of the Sudan has been very slow, with only 10,000 persons employed in industrial plants. This growth has been hampered by three major factors: a lack of applied research to give direction to the development; a lack of skilled manpower; and a lack of investment capital to provide the necessary plants. The greatest potential for growth in Sudan lies in this latter area, and the most promising industries include cotton processing and finishing mills, as well as plants for paper and cement manufacture and gum arabic processing.

The cattle industry, presently important locally but very primitive, could be developed into a thriving economic force. Chief reason is that much of

the land area of the nation is suitable for grazing, and a relatively low degree of skill is required to increase the output. Meat processing plants would be a prime necessity in order to build an export industry around cattle raising.

There is very little, if any, applied research being carried on in the Sudan now, though the governing group is aware of the need for this activity and anxious to encourage it.

Education in Sudan is developing and has a promising future. Nine teachers colleges have been established, and their effect will be felt more with each passing year as the number of grade and high schools increase. Two important advanced schools are now functioning—Khartoum University, which is graduating five chemists and physicists each year, and Khartoum Technical Institute, which annually provides the nation with approximately 200 engineers in all disciplines. Working from this educational base, the Sudan can look forward to a useful and effective graduate total during the next two decades. But for the present—as is true throughout the continent—the supply of educated persons, particularly scientific and technically trained persons, is woefully inadequate.

It is apparent that Sudan's gross national product must be increased to provide the government with funds for development of the country. The country's income from exports must bring new money into it, and this money in turn must be used to develop the economy. The generator required to start this current flowing is applied research, to give impetus and direction to industrial and agricultural growth.

The situation in Sudan is far from unique. With only details varying, it is the same in most of the other new nations of Africa. And it has been the same in the developing nations of Asia and South America. In each case, the point of departure for economic growth is the establishment of some means for applied research.

Applied research beachheads in Africa have already been established in Kenya, Uganda, and Nigeria, which have made modest beginnings in the organization of research facilities. But they, and the other emerging nations of the dark continent, will require much help before the maximum potential can be derived from their resources.

All of the new nations have tropical agricultural economies with varying degrees of mineralization; all produce commodities similar to those of the developing Latin American and Asian countries; and almost all are hampered by one-product economies.

The most important existing agricultural resources in these countries are cotton, coffee, cocoa, peanuts, rubber, and palm products. In minerals now exploited, copper, diamonds, and iron ore predominate.

To develop stability and to avoid violent swings in prosperity because of rapidly fluctuating world commodity prices, the new countries of Africa must move away from dependence on one product or resource. They must diversify their exports. And they must learn to add value to their resources through processing and manufacturing, so that the maximum amount of foreign exchange can be earned.

Aside from providing diversified products for export, the establishment of new industry has measurable effects on the internal life of a nation. Statistics from the United States demonstrate the effect of a new factory on a local economy. Estimates show that 100 new factory workers in a community mean 112 additional households, $590,000 increase in personal income per year, $270,000 more bank

Majority of new independent countries depend on a single crop and employ primitive marketing and transportation.

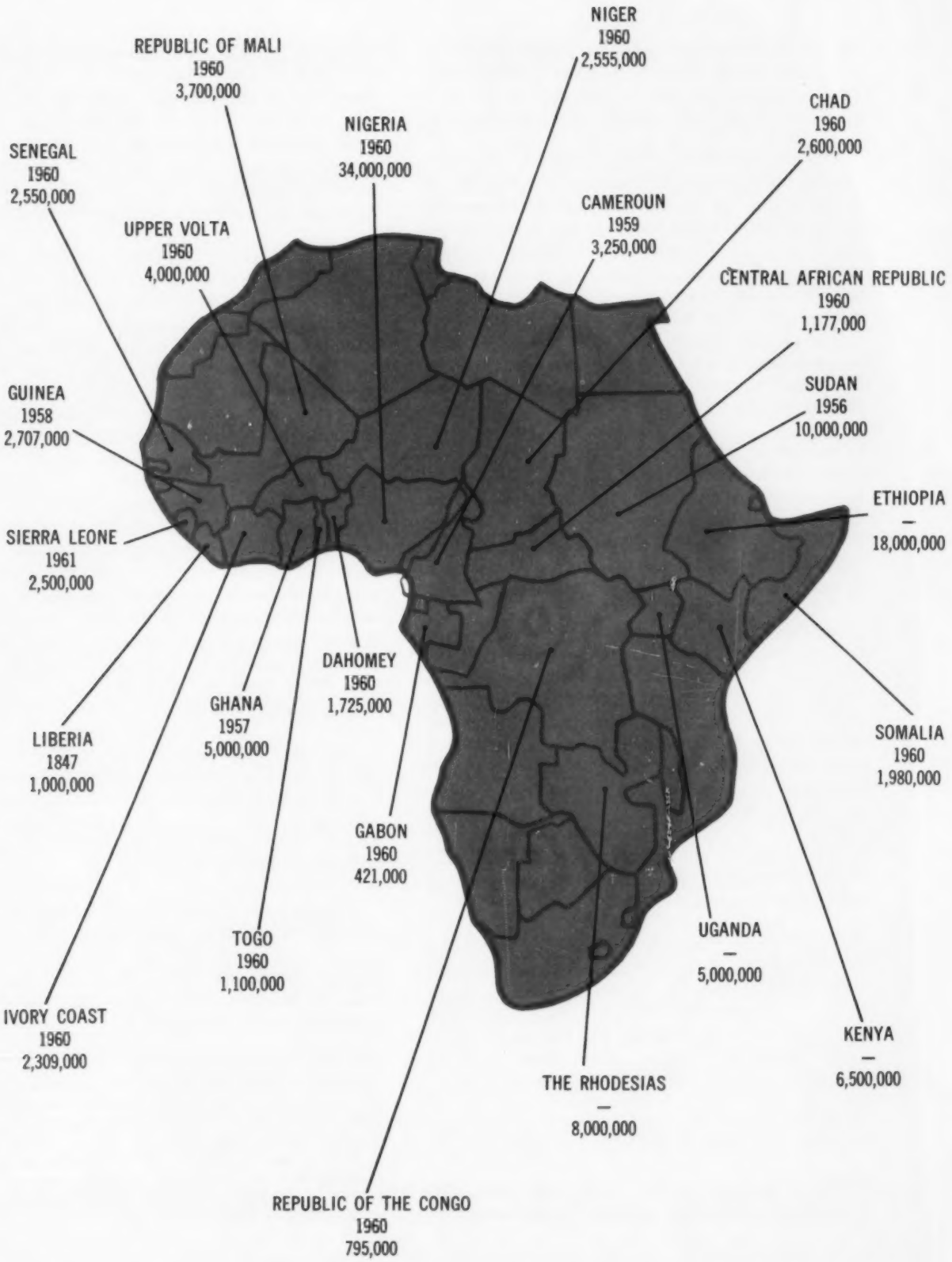
COUNTRY	CHIEF EXPORT CROPS AND PERCENT OF EXPORT INCOME	TOTAL ACRES AVAILABLE FOR PRODUCTION*	ACRE USAGE* 1. ARABLE 2. PASTURE 3. FOREST	UNEXPLOITED RESOURCES	TECHNICAL AND SCIENTIFIC GRADUATES PER YEAR	GREATEST NEED
CAMEROUN 166,570 sq. mi.	COCOA 54% COFFEE 15% BANANAS 8%	70,917	17,927 24% 19,768 27% 33,852 47%	DIVERSIFICATION OF CASH CROPS TIMBER	NONE	MORE TRANSPORTATION IMPLEMENTATION OF CAMEROUN PLAN TO DOUBLE LIVING STANDARDS
ETHIOPIA 409,205 sq. mi.	COFFEE 50% HIDES 10%	168,000	27,181 16% 133,434 79% 7,413 5%	MINERAL DEPOSITS CATTLE INDUSTRY	25	RAIL TRANSPORT TO SEA MANUFACTURING
GHANA	COCOA 68% MANGANESE 11%	50,687	13,121 26% 4,942 10% 32,624 64%	EXPORT OF BAUXITE PRODUCTION OF ALUMINUM	30	AGRICULTURAL DIVERSIFICATION MANUFACTURING
IVORY COAST 123,282 sq. mi.	TIMBER 70% COFFEE 16% COCOA 8%	?	?	MINERAL DEPOSITS	NONE	AGRICULTURAL DIVERSIFICATION TO AVOID SINGLE CROP DEPENDENCY
KENYA 224,960 sq. mi.	COFFEE 28% TEA 11% SISAL 11%	37,262	3,953 10% 29,652 79% 3,657 10%	CASH CROPS	12	MANUFACTURING FACILITIES CONVERSION TO MODERN FARMING METHODS
LIBERIA	RUBBER 94%	14,719	4,479 30% 640 4% 9,599 65%	IRON ORE DIAMONDS	60 (PRE-ENGINEERING ONLY)	EDUCATIONAL FACILITIES DIVERSIFICATION PROGRAMS
NIGERIA 373,250 sq. mi.	PALM NUTS 57% COCOA 23% PEANUTS 17%	?	?	MINERAL DEPOSITS	60	MANUFACTURING MINING FACILITIES
RHODESIAS 488,654 sq. mi.	?	253,393	93,544 37% 13,190 5% 146,668 58%	MINERAL DEPOSITS TIMBER	10	MANUFACTURING FACILITIES
SIERRA LEONE 27,925 sq. mi.	COFFEE COCOA SUGAR CANE	16,098	9,921 61% 5,436 34% 741 5%	MINERAL DEPOSITS	NONE	EXPLOITATION OF NATURAL RESOURCES
SUDAN 967,500 sq. mi.	COTTON 60% GUM ARABIC 10%	292,423	5,888 2% 60,386 20% 226,148 77%	CATTLE RAISING TIMBER	210	DIVERSIFICATION PROGRAMS COTTON MFG. FACILITIES
TOGO 31,000 sq. mi.	PALM NUTS PALM OIL COCOA COFFEE	3,380	2,391 71% 492 14% 492 14%	CASH CROPS PHOSPHATE MINING	NONE	MINING AND MANUFACTURING FACILITIES
		* ADD 000	* ADD 000			

Chart shows extent of problem confronting selected African countries. Situation is similar in most nations below Sahara.

deposits, 107 more passenger car registrations, and a population increase of 296. These same figures would not apply in Ghana or Nigeria, but a similar impact would be felt. Industry is the well-spring of an economy in Africa as well as in Ohio.

Aware of the need for expanded industry, each of the new countries is in pursuit of foreign investment capital. But a major capital investment alone may not be the answer—and, in fact, might prove disastrous. Industrial development backed by large amounts of capital must be preceded by careful and extensive laboratory and techno-economic research. The feasibility of basing a new industry on existing local resources must be proven. Even the transplanting of known industrial processes from advanced countries requires investigation. There have been many failures by industrial entrepreneurs caused by the lack of investigation into the effect of local variations in raw materials and climate on the process and the product.

Such failures at this time in Africa would be intolerable, not only because of the waste of scarce


NIGER
1960
2,555,000
REPUBLIC OF MALI
1960
3,700,000
CHAD
1960
2,600,000
NIGERIA
1960
34,000,000
SENEGAL
1960
2,550,000
CAMEROUN
1959
3,250,000
UPPER VOLTA
1960
4,000,000
CENTRAL AFRICAN REPUBLIC
1960
1,177,000
GUINEA
1958
2,707,000
SUDAN
1956
10,000,000
ETHIOPIA
—
18,000,000
SIERRA LEONE
1961
2,500,000
DAHOMEY
1960
1,725,000
GHANA
1957
5,000,000
LIBERIA
1847
1,000,000
SOMALIA
1960
1,980,000
GABON
1960
421,000
TOGO
1960
1,100,000
UGANDA
—
5,000,000
IVORY COAST
1960
2,309,000
KENYA
—
6,500,000
THE RHODESIAS
—
8,000,000
REPUBLIC OF THE CONGO
1960
795,000

capital, but also because failure would deter other potential entrepreneurs. Experience in other newly developing areas has shown that rational development can be aided by applied industrial research.

There is research in Africa at present. The Commission for Technical Cooperation in Africa South of the Sahara reports the existence of 416 research organizations. These, however, are primarily engaged in basic research in agriculture, biology, tropical medicine, entomology, and sociology. Most of them are small, with scientific staffs of less than five persons. Only four of these organizations are official applied research institutions aimed at total resource development. In addition, there are a few industrial research laboratories attached to some private companies in South Africa and Rhodesia.

The major limitation on the growth of vital industrial research in Africa is not money, as might be expected, but the shortage of technically trained Africans. Trained men are beginning to become available, and the number will inevitably increase in future years. But it will not increase fast enough to meet the needs of the people in Africa for decades.

Meanwhile, the companion problem of stimulating industrial growth must be solved. It cannot wait until the educational problem is worked out. On the one hand, African scientists and engineers won't be available in sufficient numbers for years; on the other hand, Africa begs to be developed immediately by its own people. One answer to this dichotomy is the establishment of institutes of applied research, supported by some governmental ministry or agency in each of the more advanced countries of Africa. At first, such institutes would be staffed by scientific personnel from the advanced nations of the world.

Such "pilot" research institutions have been established with the assistance of Armour Research Foundation in Mexico, Burma, Colombia, Venezuela, and Afghanistan. Similar institutes have been set up in Central America, Ceylon, and several other developing countries. Often, these institutes are the only laboratory facilities in the country.

The purpose of such industrial research laboratories is to prime the research pump in each country.

One of the first projects of the institute would be a thorough search of previous studies and the undertaking of new studies to determine the possibilities for new industries. With the direction thus defined, research and development would be started. The new industries would be developed according to their economic ability to utilize available mineral, agricultural, and marine resources. A second goal would be the establishment of industries based on by-products and wastes from existing industries.

The existence of the institute can help to attract financing, since it would be available to carry out feasibility studies and investigations on the technical and economic soundness of projects for interested local and foreign investors. After the financing had been arranged, the institute would provide the research necessary for the transplanting of known industrial and agricultural processes from other countries, and would provide the techno-economic studies for the location of new plants.

The make-up of the institute might vary, but its base should be broad and flexible. Ideally, its staff should include one or more biochemists, organic chemists, chemical engineers, analytical chemists, and physicists. In addition, it should have a mineralogist-metallurgist, a forest-products chemist or engineer, a ceramics engineer, an engineering economist, a mechanical engineer, and a technical librarian. All of these specialists are in short supply in Africa, and will remain so for at least another decade.

There is little doubt that Africa has the resources, the manpower, and the markets to provide for healthy industrial growth in the future. It has two limitations. The first is the present lack of technically trained Africans. The second is the lack of sufficient industrial research.

If an immediate means of industrial research does not become available, then the research will have to wait until the educational level of each country is raised to the point where it can initiate its own research. Such a delay may be fatal to many of these new small countries.

In addition to studying the status of industrial research in Africa, Irving D. Canton, who is assistant director of International Research, has participated in ARF's organization programs for the governments of Mexico, Colombia, and Burma. He was also team leader of a mission to study the feasibility of developing Brazil's low-grade iron ore deposits and was instrumental in establishing ARF's European Technical Operations Group in the Hague.

ARF IN PRINT

Staff members of Armour Research Foundation are frequent contributors to scientific journals. Among articles recently published by them are the following:

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ESCAPE IN SPACE

The safety of our astronauts is a prime consideration in the U.S. program for space exploration. In all phases of flight, from launch to recovery, they will be protected

BY WILLIAM H. BAIER

Manned space flight is now a reality and soon will extend beyond the threshold of space as we probe toward the moon and beyond. A Redstone propelled Alan Shepard through a ballistic trajectory over the Atlantic Ocean in April. Similar flights will follow and then, boosted by an ICBM Atlas, the first U.S. manned space vehicle will orbit the earth at an average altitude of about 120 miles.

At another time, a boost-glide vehicle, descendant of today's conventional aircraft, will also put a man into space, but at altitudes of 50 to 100 miles. Such a vehicle, recently studied at Armour Research Foundation, will be boosted by either solid—or liquid-fueled multi-stage engines at near-satellite velocities. After its fuel has been exhausted, the vehicle will become a glider sustained by aerodynamic lift. It will encircle the globe and land at its launching point after a flight of a few hours.

All of the space vehicles present grave dangers to the men who pilot them. The fiercely burning rocket engines, meant to hurtle them into space, can explode with little warning. The vehicles themselves can seriously malfunction while 100 miles or more from the earth.

It is an appalling loss of time, energy, and money for a multi-million dollar rocket to explode in an envelope of orange flame before it even leaves the launching pad. It is disheartening to have an instrument package lobbed into the wrong trajectory because of a minute mechanical failure. But infinitely more important than any of these is the life of the man confined in the capsule at the top of the rocket. To protect his life, engineers and scientists have studied every phase of all types of flights—to devise methods of escape so that he can be safe in each stage of flight.

The problems of an effective escape system in a space vehicle are compounded by the variety of dangers which may confront the astronaut. The escape system must be versatile enough to assure his safety from the moment he enters the vehicle on the launching pad until the time he is free of his escape capsule or when he finally lands his glider. Either orbital or sub-orbital flight can be divided into seven phases, each of which presents its own problems of safety.

The pre-launch phase lasts from the beginning of the countdown to rocket ignition. During this

phase, which should last 20 to 30 minutes under normal operating conditions, the astronaut enters the vehicle, the fuel and oxidizer are loaded, and the countdown is made.

During this stage, only an explosion of the booster fuel supply would require an escape from the vehicle. Malfunction in the guidance system, trouble in the hydraulic or electrical circuits, or failure in the cabin's environmental system, would result only in forestalling the countdown.

Research has shown that an impending booster explosion can be detected at least two seconds before it occurs by rather pronounced symptoms in the propellant tanks or thrust chambers. Given this short warning, electrical relays release the clamps holding the escape body to the booster and ignite an escape rocket. This will propel the capsule and its occupant to a point nearly a mile from the disaster area—a distance necessary if the pilot is to escape the conflagration of the rocket's fuel and oxidizer, which may cover an area of several hundred yards.

The thrust build-up of the ejector rocket must be carefully controlled to stay within human tolerance regarding rate of onset and acceleration. Twenty G's of acceleration, presumably top limit of man's tolerance, will be experienced by the pilot for nearly a second in the ARF-suggested design. When the ejector rocket burns out, only one and a half seconds after the initial detection, the capsule will be several hundred feet from the booster, which explodes one-half second later. The pressure wave from the enormous explosion, traveling up to twice the speed of sound, overtakes the capsule about 400 feet from the point of explosion. Because the blast pressure diminishes as the wave expands outward, the overpressure experienced by the capsule when overtaken by the wave (3 to 10 psi) should not be damaging.

The escape body continues upward after being overtaken by the pressure wave, until it reaches a peak altitude of over 2000 feet. Shortly after this point, a parachute is released and the capsule descends to the ground, a safe distance from the inferno raging in the vicinity of the launching pad.

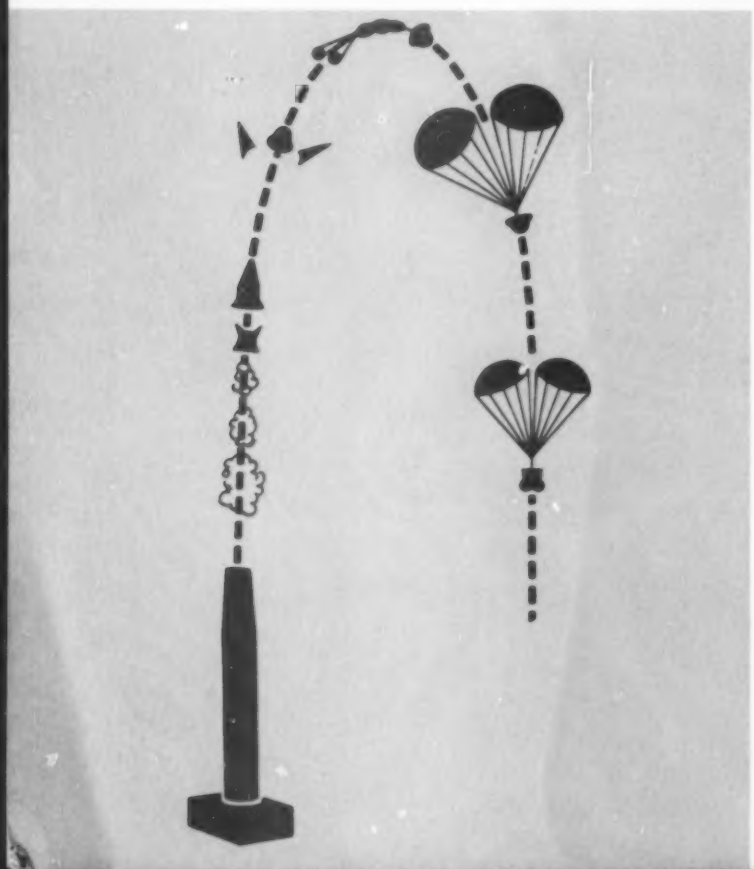
The explosion problem is also the principal reason for escape during the launch phase, which begins at the ignition of the booster engines and lasts

from 2 to 10 seconds, depending upon the booster and launch complex. At this stage, the boost unit builds up to full thrust, and the vehicle begins a restrained, controlled lift-off. During this time ground personnel continuously monitor the rocket's operation. A decision to initiate escape procedures during this phase would probably be made by the range safety crew or by automatic means. In case of a cabin atmosphere malfunction, the pilot would fire off the ejector rocket.

As the vehicle is released from the restraining arms of the launching platform and from the umbilical cord leading to electrical connections, the boost phase begins. Depending upon the given booster configuration, this stage lasts 300 to 400 seconds.

During the earlier part of this phase, the possibility of explosion will remain the most crucial problem, as it was on the launching pad. But as the vehicle gains altitude, two other possible problems arise. These are a loss of thrust from the rocket motors and guidance failure. Ground-based computer units, constantly calculating predicted position and velocity at the termination of rocket thrust,

If mishap should occur during launching phase, capsule would be automatically propelled a safe distance from launching pad and parachuted to earth.



are quick to sense the consequences of a malfunction in either the thrust unit or the guidance system. Should the velocity of the vehicle or its orientation fall outside of predetermined limits, the ground monitor is quickly notified of an impending mission failure. The escape capsule is then ejected from the rest of the vehicle before the range safety officer destroys the booster unit.

At the end of the boost phase, during which the fuel is exhausted, the manned satellite enters the orbit phase of its trajectory—or glide phase, if the vehicle is a boost-glider. The orbital period at the altitudes considered by ARF would last about 100 minutes. For the glider, the glide phase should last about 60 minutes. Since the fuel supply has been consumed, there is little possibility of a catastrophic explosion during this phase.

The most dangerous mishap to be guarded against in this phase is excessive tumbling at high altitudes. During the glide portion of its trajectory, the aerodynamic control surfaces of the boost-glide vehicle lose their effectiveness in controlling vehicle orientation. No aerodynamic means are effective in dealing with the disturbing torques exerted on the vehicle by internal explosions, off-center staging impacts, or motion of the crewman or internal equipment. If these movements exceed the capacity of the boost-glide or satellite vehicle jet reaction attitude control system, the vehicle may begin to tumble at a rapid rate. It will become necessary for the crewman to eject the escape capsule if this tumbling approaches the human danger level.

Even small torques will affect a spacecraft tremendously under near-vacuum conditions. The torque necessary to dial a telephone, for instance, would cause a satellite of the type considered here to turn through 180 degrees in 90 seconds.

If the escape capsule is ejected during tumbling, an emergency jet reaction system built into the capsule will be utilized by the crewman, or activated by automatic means, to bring the capsule to a stabilized position as soon as possible.

The weightlessness that the crewman will experience during the orbit or glide phase is not likely to endanger him. Neither should radiation pose an immediate threat to anyone under an altitude of 500 miles. Nor does the prospect of colliding with

micrometeorites or with larger-sized meteorites seem an imminent danger to low altitude spacecraft. Studies indicate that at the altitudes discussed in this article a seven-foot diameter sphere will be hit by a meteorite of larger than one inch in diameter only once every 250 years.

The return of the spacecraft to the earth's surface is termed the re-entry phase. For a space vehicle possessing lift, this stage may be in excess of two hours, while for a blunt-nosed or drag-shape satellite the time is reduced to about 15 minutes. Re-entry for the boost-glider requires about an hour.

Upon descending to an altitude of about 70,000 feet, the space vehicle slows down to Mach 2. At this speed, stabilizing as well as retardation parachutes may be opened to slow down the vehicle further.

Problems encountered in this phase are similar to those found in the preceding stage. Temperatures or accelerations beyond human endurance are the crucial considerations.

The hazards that will be encountered during the landing phase will depend upon the method used to land. For a drag-type satellite vehicle, landings will most probably be made beneath a chute. The boost-glider would be landed in the conventional manner. Errors in both boost and glide phases, however, would present almost insuperable problems to a boost-glider seeking a suitable landing area following a global mission. Operational techniques for vehicle landings, in fact, remain to be developed.

The decision to escape from a boost-glider in this phase would be made by the crewman, whereas escape procedures from a space vehicle under a chute would be initiated by automatic sequences. A malfunction concerning the cabin atmosphere at these lower altitudes could be partially corrected by venting to the outside atmosphere at about 35,000 feet.

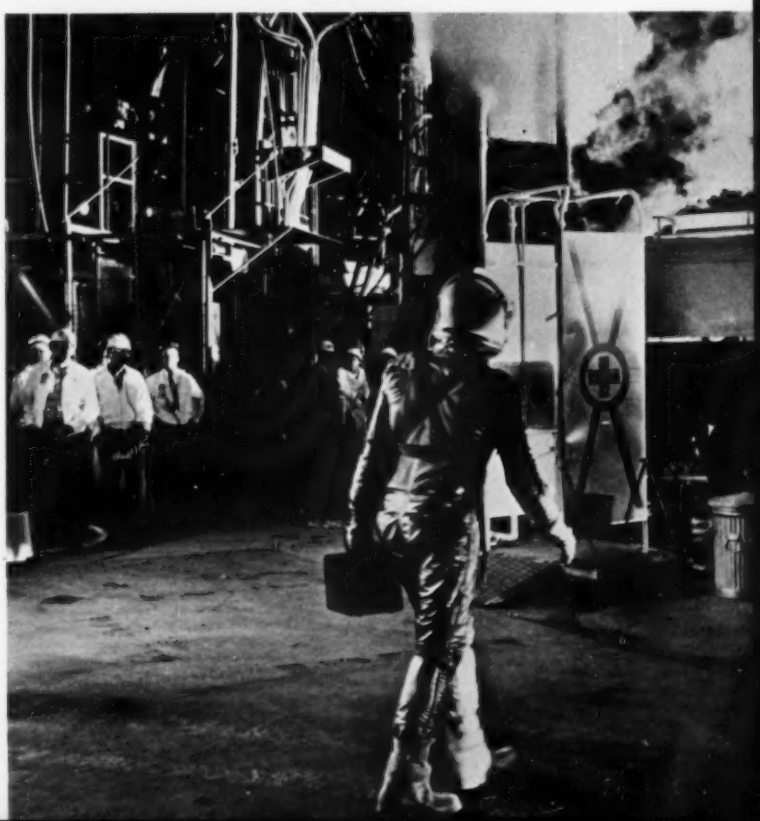
The final phase of the vehicle trajectory—recovery—begins the instant the vehicle is brought to rest and ends when the pilot is removed. This phase may last as long as 72 hours under normal circumstances.

The escape equipment needed during this stage includes food, shelter, and medical supplies for the crewman as well as some means by which he can be located. These include radio and radar (S and X band) flashing lights, chute gores of alternating orange and white, radar chaff, SOFAR bombs, and dye markers. The escape body itself must be able to float in water, absorb the ground impact at 30 feet per second, and provide the necessary shelter and survival equipment for the crewman.

As the space frontier is pushed back, the problems that face the escape body designer increase right along with those that harrass the aerodynamicist and the propulsion systems analyst. Complete protection for the pilot demands so much added weight that the performance of the space vehicle is impaired. Future efforts in design must seek the proper reconciliation between greater personal safety for the pilot and the uncompromised execution of the space vehicle's mission.

Dr. William H. Baier, supervisor of space systems and biomechanics at ARF, recently directed a preliminary study of escape procedures from satellite and boost-gliders. Dr. Baier has been associated with many armament, ordnance, and aerospace projects at the Foundation, including the design or development of an atomic mortar, antiaircraft rocket weapons, and extra-terrestrial probe mechanisms.

Commander Alan Shepard approaches rocket that thrust him briefly through space. Trip was preliminary step in putting U.S. astronaut into orbital flight.



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